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FAST-CLOSING VACUUM FOR HIGH-CURRENT PARTICLE ACCELERATORS

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Fast-closing vacuum valve for high-current particle accelerators

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ABSTRACT

A fast-closing vacuum valve for a high-current particle accelerator was fabricated and tested. The 51-mm (2-in.) ball valve is located in the accelerator beamline and closes within 5 ms if a vacuum loss is detected in the beamline. The valve is activated by a pressure-rise detector that initiates a capacitor bank to discharge its current through two solenoids. The impulse force closes the valve and activates an air-powered, cam-type mechanism. This mechanism forces a diaphragm equipped with an O-ring housing against the ball valve to produce a high-vacuum seal in the beamline. The valve functions reliably and is simple to reset after each firing. Only the metal energy absorbers, which are deformed during valve closure, require replacement. Another desirable feature of this valve is that its inner body contour is essentially symmetrical to the beamline. Thus, the magnetic field produced by the large return current is uniform and does not deflect the particle beam.

INTRODUCTION

A powered ball valve (Fig. 1), which closes within 5 ms, was designed and built to protect the high-vacuum region of a particle accelerator.[1] The 51-mm (2-in.) bore valve is located in the beamline (Fig. 2) between the end of the accelerator and a 8-m (26-ft) length of evacuated beam pipe, which extends to the experimental test setup. The beam exits the pipe into the experimental tank through a fragile window of pyrolytic graphite foil. Window rupture causes a fast inrush of air, which could damage components in the accelerator gun. The fast closing valve is triggered by a pressure-rise detector to maintain the high vacuum in the accelerator.

A previously built fast valve[2] employing an explosively-driven polyethylene plug was successfully used on low-current particle accelerators. Because the inner bore of this valve is not symmetrical, a large return current would produce an offcenter magnetic field that would deflect the beam.

The fast valve described here was designed and built for use in an accelerator that has a 10-kA, 40-ns repetitive electron-beam pulse. These high currents require a large (51-mm) bore and a cylindrical inner wall that is symmetrical about the beamline. The valve has an O-ring seal mechanism for creating a high vacuum (10^{-6}-torr) seal in the beamline. By replacing the metal energy absorber, the valve can be used successively to protect the vacuum components of the accelerator.

I. DESCRIPTION OF VALVE OPERATION

During accelerator operation, the valve is in the open position (see Fig. 3). The position of the cam push rod is maintained by the release latch, which opposes the closing force exerted by a pressurized air cylinder.

If the fragile window in the accelerator beamline fractures, a pressure-rise detector initiates a capacitor bank to discharge its current through two solenoid coils. The current in the coils gives an inductive impulse to the conductive moment arm causing it to rotate. This rotation is transmitted, by a shaft, to the ball valve that closes (Fig. 4) and blocks the inrush of air. The rotation is safely terminated when the conductive arm is stopped and captured by a metal energy absorber.

A vacuum seal is achieved by forcing the cam housing, equipped with an O-ring, firmly on the ball valve immediately after its rotation to the closed position. This is accomplished by a lug on the conductive moment arm striking the raised lip of the release latch. This disengages the cam push rod forcing it downward by the pressurized air cylinder. The downward motion of the push rod is directly connected to a yoke and cam rollers. The downward motion of the cam rollers forces the cam housing firmly upon the ball valve and secures a vacuum-tight seal. The vacuum integrity is also maintained by a bellows, diaphragm, and shaft seal.

After the ruptured window is replaced and vacuum restored, the valve can be returned to its open position with the following procedure:

1. Withdraw the air cylinder until the release latch engages a notch in

the cam push rod. The air cylinder is then repressurized. 2. Manually rotate the conductive moment arm until it contacts the solenoid coils. A position switch is activated by the conductive moment arm in the open position, and this gives a local and remote indication of the position. 3. Replace the metal energy absorbers. 4. Recharge the capacitor bank.

II. ELECTRONIC FIRING CONTROL

The block diagram of the electronic control circuitry is shown in Fig. 2. The control chassis is used to charge the capacitor bank and has indicators to show that the valve is open and armed for firing. The control chassis is also interlocked to the accelerator, so the beam cannot be fired when the valve is closed. When a foil window failure occurs, a signal from the ion-gauge, vacuum-failure detector triggers the control/firing chassis. The capacitor bank is discharged through two coils to drive the valve closed. Each coil is spirally wound with 10 turns of 4 × 1.5-mm copper strips and has an inductance of approximately 2 μH. The capacitor bank is made up of six 250-μF, 1500-V capacitors in parallel. At a 1500-V charge, the total stored energy is 1688 J. The measured peak current through the coils at this charge is 24 kA with a 100-μs risetime.

III. TESTING AND RESULTS

The closing time of the valve was measured for various stored energies at atmospheric pressure using a light beam passing through the bore of the valve and illuminating a silicon photodetector. At 800 J the closing time was 13 ms (Fig. 5), while at 1500 J it was 3 ms. Because the trigger delay time from the pressure detector to the ignition firing chassis is less than 1 ms, it is anticipated that the total time between window rupture to valve closure will be less than 5 ms.

In conclusion, we found that the valve functions reliably and its closure time is repeatable. The valve is simple to reset after each firing and requires only replacement of the metal energy absorbers.

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[2] R.C. Wolgast and J. W. Davis, IEEE Trans. Nucl. Sci., **NS-16**, 954 (1969).

FIGURE CAPTIONS

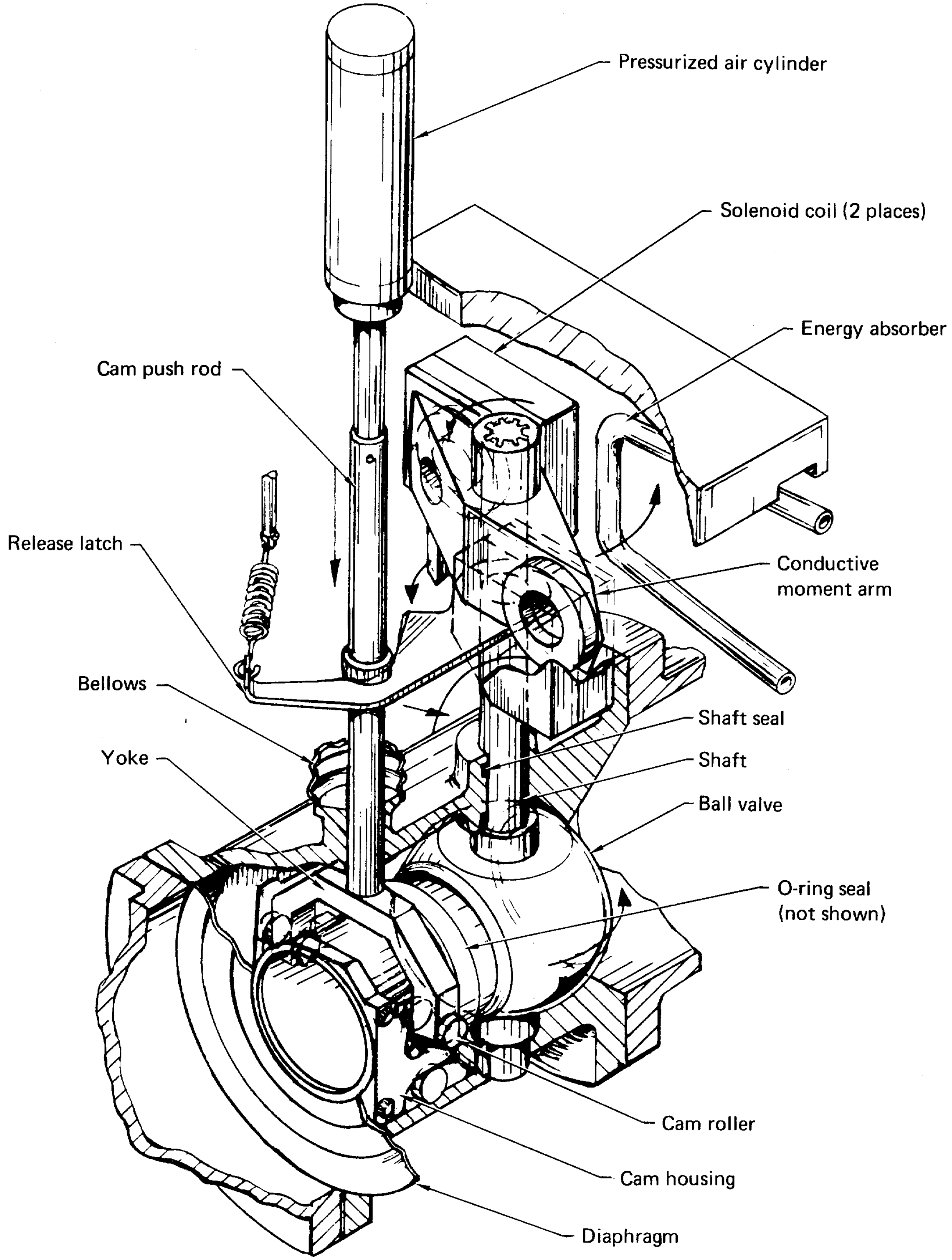
Fig. 1. Fast-closing vacuum valve for a large-current particle accelerator. The arrows indicate direction of motion.

Fig. 2. Fast-valve firing layout in relation to the accelerator.

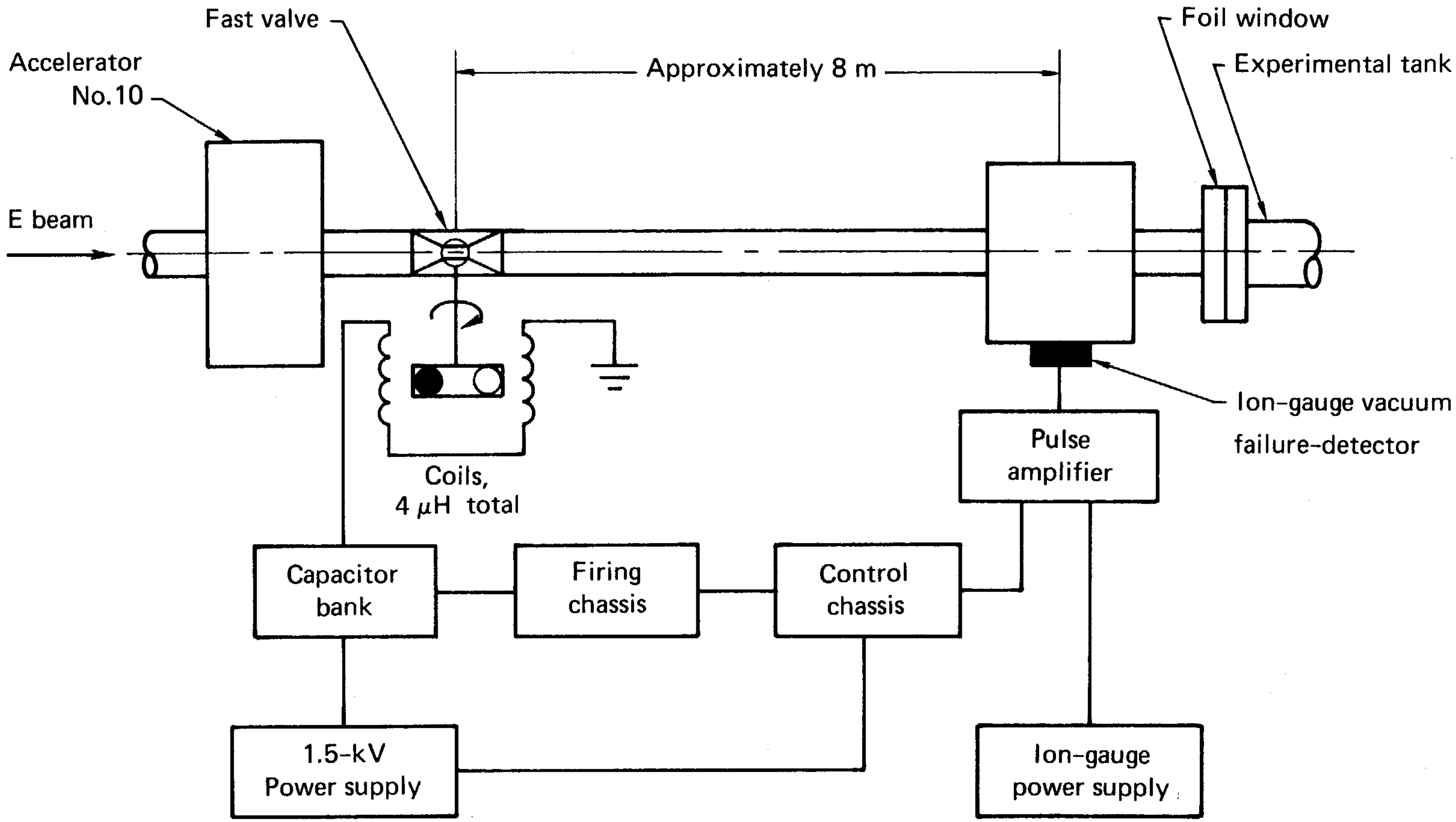
Fig. 3. Fast-closing vacuum valve in the open position. a. Top view. b. Side view.

Fig. 4. Fast-closing vacuum valve in the closed position. a. Top view. b. Side view.

Fig. 5. Measured closure time as a function of capacitor-bank stored energy.

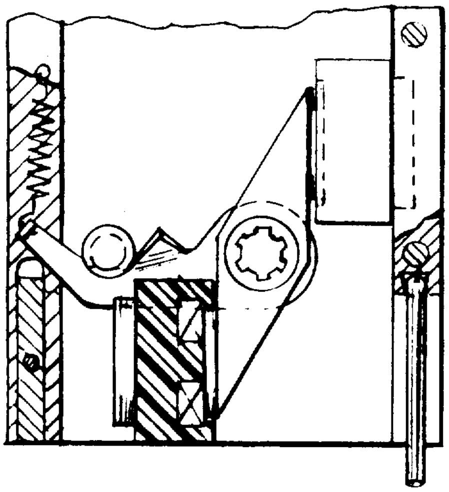

Pressurized air cylinder
Solenoid coil (2 places)
Energy absorber
Cam push rod
Release latch
Conductive
moment arm
Bellows
Shaft seal
Yoke
Shaft
Ball valve
O-ring seal
(not shown)
Cam roller
Cam housing
Diaphragm

Hanson - Fig. 1

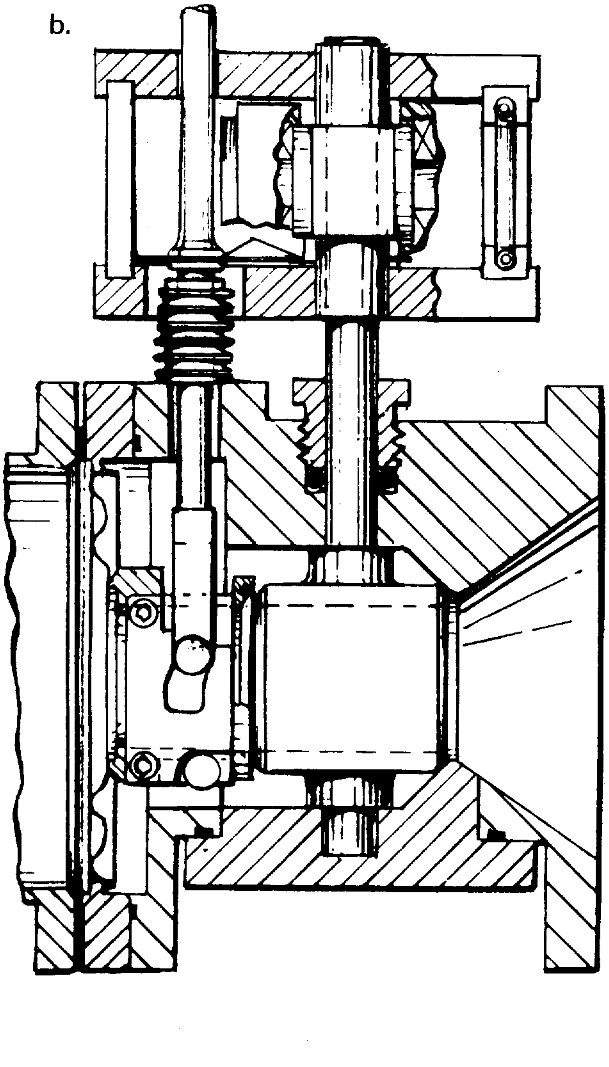

Fast valve
Accelerator
No.10
Approximately 8 m
Foil window
Experimental tank
E beam
Coils,
4 μH total
Ion-gauge vacuum
failure-detector
Pulse
amplifier
Capacitor
bank
Firing
chassis
Control
chassis
1.5-kV
Power supply
Ion-gauge
power supply

Hanson - Fig. 2

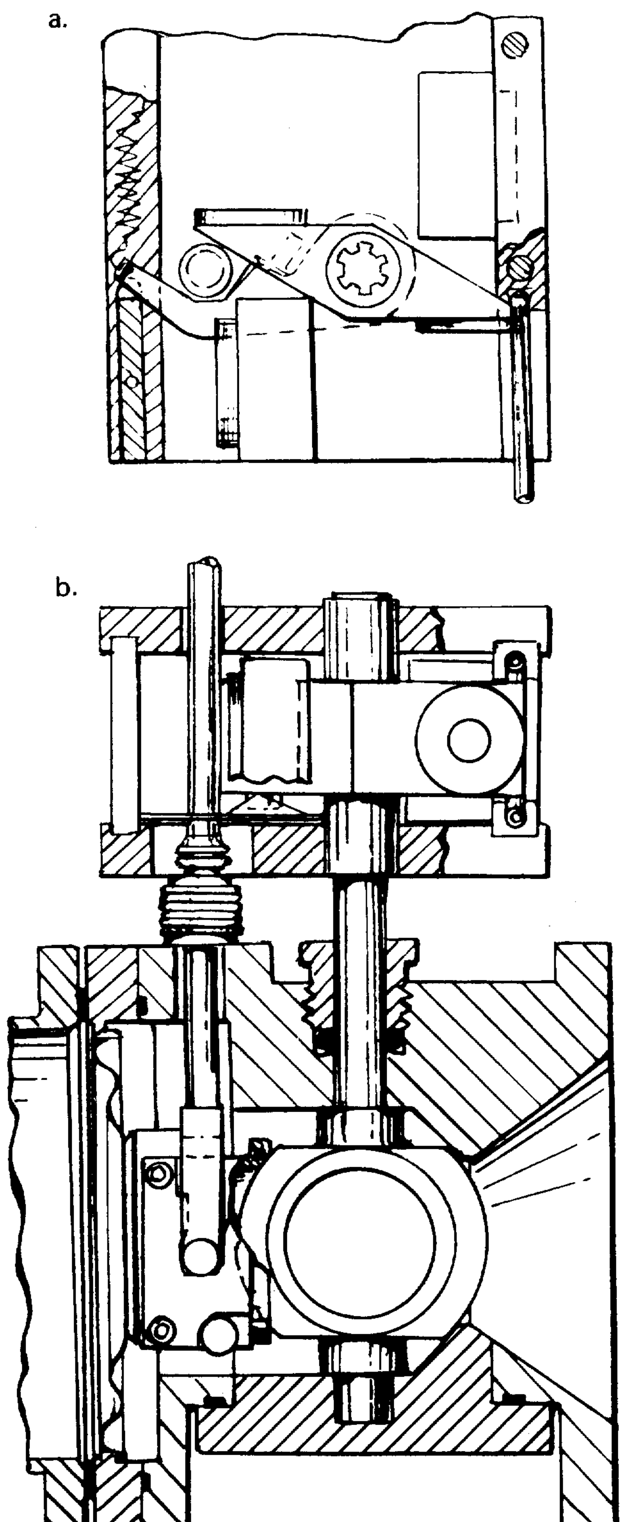
a.



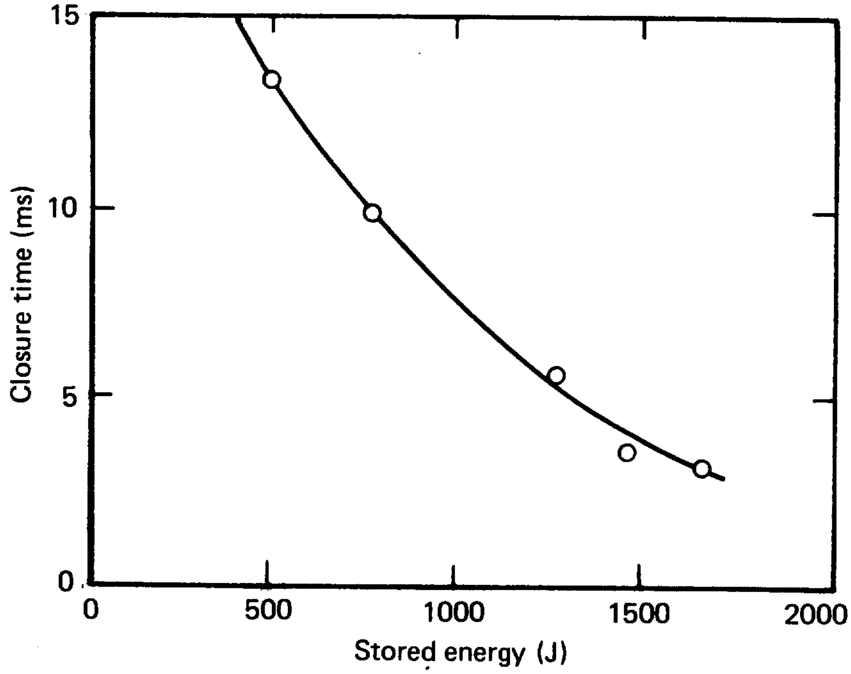
b.



Hanson - Fig. 3



Hanson - Fig. 4



Hanson - Fig. 5